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The role of biofuels in China's transport sector in carbon mitigation scenarios

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Abstract

A bottom-up model, China-TIMES was developed and carbon mitigation scenarios were designed to discern the role the biofuels in China's future transport sector. The development of biofuels in China will be restrained by technology progress, food security concern and land availability. Results suggest that biofuels will reduce 0.43 Gt of CO_2 emissions in 2050 in the CM30 scenario and contribute to 35% of the total reduction. Also it can be concluded that bioethanol will be more influenced by the electrification than biodiesel and biojet fuels due to its easier substitution by electricity. Biofuels will be indispensable in China's transport decarbonization, and pertinent and coherent policies will be needed to propel the sustainable development of biofuels.

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Keywords: TIMES model; transport sector; biofuel; carbon mitigation; indirect emission

1. Introduction

There is a broad consensus that human beings have been confronted with great challenges to cope with climate change and global warming issues. Transport sector plays an important role in the energy system, oil demand, and CO_2 emissions. In 2010, transport contributed 22% to global CO_2 emissions [1]. As the largest emerging country and the world's most populous nation, China has experienced a boost in transport sector and this trend is likely to keep on due to the expectable strong demands. At the same time, the oil import dependency in China was nearly 59% in 2012 [2], indicating a latent threat to its energy security.

Decarbonizing the transport sector is a quite fundamental challenge and it can be tackled through various approaches. As one of the decarbonization options, biofuels can offer an opportunity to reduce

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carbon emissions in transport sector and enhance energy security. Nowadays, most of the biofuels are produced by USA (mainly corn ethanol) and Brazil (mainly sugarcane ethanol) (Fig. 1).

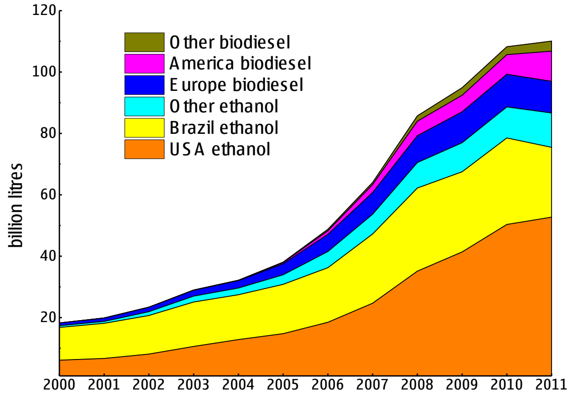

Fig. 1. Biofuels production in 2000-2011. Source: U.S. Energy Information Administration, 2014.

Biofuels can be generally divided into conventional biofuel and advanced biofuel. The former includes sugar- and starch-based ethanol, oil crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion, while the latter mainly includes cellulose-based ethanol, biomass-to-liquids (BtL)-diesel and bio-synthetic gas (bio-SG) [3]. Researches on biofuels principally revolve around the resource potential and distribution [4], technology proceedings [5, 6], cost and efficiency [7, 8], life cycle emissions [9, 10], and food security. Generally speaking, the development of biofuels should coordinate the relationship among food security, arable land availability, biodiversity, and energy sustainability.

In China, the starch-based ethanol and transesterification biodiesel are already commercially available, with their production being 1.8 and 0.5 million ton respectively in 2010. In this study, bioethanol, biodiesel, and biojet fuels, which are recognized as more promising in China and have an official development plan [11], are analyzed using a bottom-up energy-economic model—China-TIMES.

2. Methodology

2.1. China-TIMES model

TIMES (an acronym for The Integrated MARKAL-EFOM System) is an economic model generator for energy systems developed by The Energy Technology Systems Analysis Program (ETSAP), International Energy Agency (IEA). In this study, China-TIMES is developed based on the China-MARKAL model to provide a technology-rich basis for estimating long-term energy dynamics with a horizon of 2010 to 2050 with the interval of five-year period [12, 13]. The model make technology choice by substitution to achieve the inter-temporal energy system least cost [14].

In order to better represent the real-world characteristics of the transport sector, a down-scaled analysis was carried out to increase the resolution of transport sub-modes and technologies in this study. In every modes or sub-modes, several technologies (mainly with different powertrain systems) compete with each other in this model. Bioethanol is presumed to be used in both conventional internal combustion engines (ICEs, 10% at most) and flex-fuel vehicles (FFVs, 83% at most).

Transportation services demand, often measured in passenger kilometer and ton kilometer, is the fundamental exogenous driver of transport-related energy consumption and carbon emissions in TIMES model. In this study, the future travel demands were derived from the discrete choice model [15].

2.2. CO_2 emissions

Transport CO_2 emissions in this paper refer to the total emissions, including both the direct emissions from vehicles and the indirect emissions from power generation, biofuels production [10], and hydrogen manufacturing. The total CO_2 emission is given by:

$$EM_{TOT} = EM_{dir} + EM_{elc} + EM_{h2} + EM_{eth} + EM_{dsl} + EM_{jet} \tag{1}$$

where the subscripts *dir, elc, h2, eth, dsl,* and *jet* denote emissions from direct fuel consumption, electricity, hydrogen, bioethanol, biodiesel, and biojet fuels production respectively.

3. Assumptions and scenarios

3.1. Socioeconomic drivers

Population for China was predicted according to the current family policy and relevant literature [16]. GDP data for base year came from the World Bank database, and it was assumed to grow with a decreasing growth rate. The annual growth rate, to be specific, will be 7.44%, 6%, 4.5%, and 3% during 2010-2020, 2020-2030, 2030-2040, and 2040-2050 respectively.

3.2. Costs

The advanced biofuels are not economically competitive without government subsidies at present (Table 1). The costs of biofuel production technologies will be hopefully diminished as a result of the R&D progress and scale economy.

Table 1. Costs of biofuel technologies in 2010.

Technology	Investment cost (million 2005$/(PJ*a))	Activity cost (million 2005$/PJ)
Conventional bioethanol[17]	12.4	20.9
Advanced bioethanol[17]	40.7	25.0
Biodiesel and biojet fuel[18, 19]	8.8	12.7

3.3. Scenarios

A reference scenario and three CO_2 mitigation scenarios are designed in this study to investigate the role of biofuels in China's transport sector (Table 2). The current policy and predictable efficiency improvement have been taken into consideration in the reference scenario. Note that the cumulative CO_2 emissions to be mitigated in carbon mitigation scenarios denote the total emissions from all the energy supply and end-use sectors.

Table 2. Scenarios definition in this study.

Scenario	Description
REF	The reference scenario
CM10	Cumulative CO_2 emissions in 2010-2050 reduced by 10%
CM20	Cumulative CO_2 emissions in 2010-2050 reduced by 20%
CM30	Cumulative CO_2 emissions in 2010-2050 reduced by 30%

4. Results and discussions

4.1. Transport final energy consumption

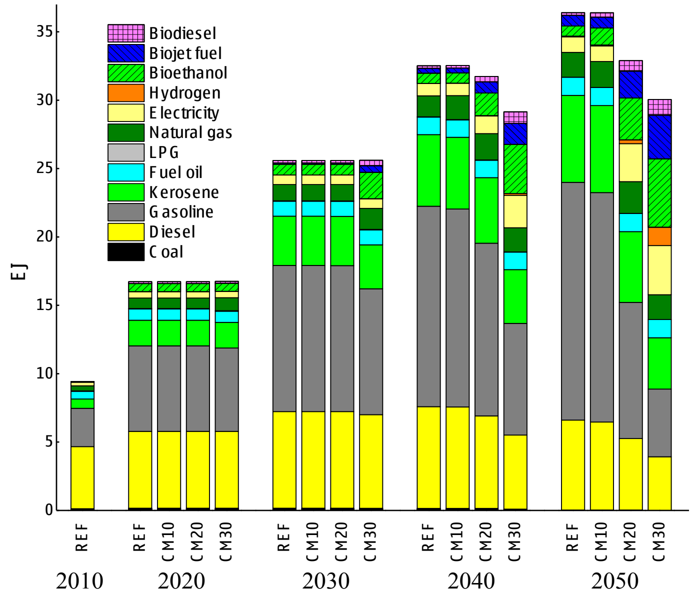

Fig. 2. Transport final energy consumption in China.

In the reference scenario, the transport final energy consumption will be almost quadruple, from 9.43 EJ in 2010 to 36.4 EJ in 2050, as a result of the sizeable growth in travel demands correlating with the economy development. Conventional liquid fuels will still dominate the transport sector, with their share slightly decreasing from 91% in 2010 to 87% in 2050, while biofuels will take up more shares, from 0.5% in 2010 to 4.7% in 2050. Results in CM10 show similar trajectories, indicating that transport sector is more difficult to decarbonize than other sectors due to persistent reliance on fossil fuels [20].

In stricter carbon mitigation scenarios, however, roles of different fuels will be significantly altered. The proportion of conventional oil fuels will shrink to 65.9% in CM20 and 46.5% in CM30, while biofuels will gradually take over simultaneously, accounting for 17.6% and 31% of the transport energy consumption in CM20 and CM30 respectively. At the same time, China's transport sector will be more electrified, which will be the principal cause for the reduction of transport energy consumption.

4.2. Transport total CO_2 emissions

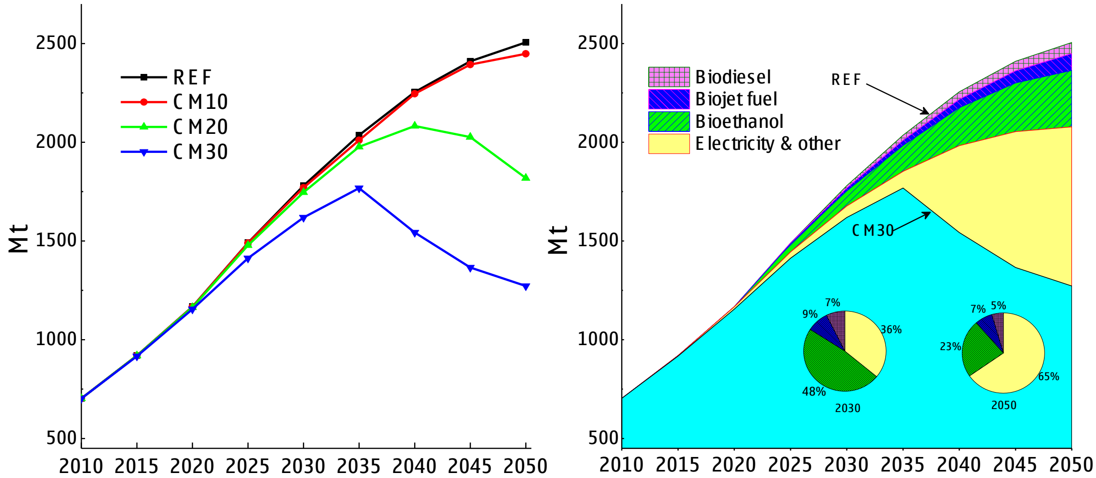

Fig. 3. (a) Total transport CO_2 emissions. (b) Contribution of biofuels to CO_2 emissions reduction in transport sector.

In the reference scenario, the transport-related total CO_2 emissions will increase substantially from 0.70 Gt in 2010 to 2.51 Gt in 2050 (Fig. 3a). Meanwhile, CM20 will see a peak in 2040 at 2.08 Gt and a reduction of 27.4% in 2050 compared with the REF. In CM30, the total CO_2 emissions will peak earlier in 2035 at 1.77 Gt and then decrease to 1.27 Gt in 2050 with a reduction of 49.2%.

Fig. 3b illustrates the contribution (or the cause) of the CO_2 emissions reduction in CM30. Three points are worth making regarding this result. First, biofuels, electric techniques, and fuel cell technology will have profound impact on the transport decarbonization and offer the possibility to reduce the transport-related cumulative CO_2 emissions by 21.6% by 2050. Second, the role of biofuels, especially bioethanol, will be more exerted in medium term, while electrification will be the long-term decarbonization direction. For example, biofuels will contribute to 64% of the total emissions reduction in 2030 while only 35% in 2050, because large amounts of low carbon power generation technologies, such as solar, biomass with CCS, begin to enter the scene after 2035, making electricity more effective to reduce emissions. Third, bioethanol will be more influenced by electrification than biodiesel and biojet fuels inasmuch as the latter are mainly employed in freight trucks and airplanes, which are not quite suitable to use lots of electricity.

5. Conclusions

In this study, China-TIMES model was developed and three carbon mitigation scenarios are designed to discern the role of biofuels in China's future transport sector. Results suggest that China will have a rapid economy growth by 2050 and have to tackle the challenges to decarbonize its transport sector. Biofuels, as one of the decarbonization options, will reduce 0.43 Gt of CO_2 emissions in 2050 in the CM30 scenario and contribute to 35% of the total reduction. Nevertheless, the development of biofuels in China will still be restrained by food security concern and land availability, and the extent to which the biomass potential can be converted into energy still require more argumentations to be determined. In addition, electrification will still be the long-term carbon mitigation option for transport sector, as long as progresses in CCS, intermittent power generation (wind, solar), and electric vehicle technologies suffice to break through the current bottleneck. Bioethanol will be more influenced by the electrification due to its easier substitution by electricity. To summarize, biofuels will be indispensable in China's transport decarbonization, and pertinent and coherent policies will be needed to propel the sustainable development of biofuels.

Acknowledgements

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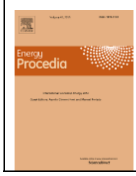

Biography

Hongjun Zhang is a Ph.D. candidate in Institute of Energy, Economy and Environment, Tsinghua University.